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CURLY TOP SYMPTOMS ON THE SUGAR BEET

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HENRY H. P. SEVERIN[1]

INTRODUCTION

Officials of sugar companies and farmers often recognize the general appearance of curly top in beet fields but usually fail when a diagnosis of the disease is required. In the literature, a large number of symptoms are recorded, but to most of these there are so many exceptions that it is difficult for the reader to select the reliable characters of the disease. When sugar companies are growing their own seeds it is extremely important to determine the percentage of diseased stechlings[2] and mother beets.[3]

During the outbreak of curly top in 1919, the percentage of diseased beets was determined in almost all of the large beet centers of California; under certain climatic conditions all leaf symptoms failed. Observations on curly-top symptoms were also made during the 1925 outbreak of the disease in the San Joaquin, Sacramento, and Salinas valleys and in years when no general outbreak occurred.

The following discussion will undertake a critical diagnosis of the disease, and will point out the resemblance of the symptoms to abnormal beet foliage and to insect injury, and the practical value to the sugar-factory agriculturist, fieldman, and farmer of knowing curly-top symptoms.

SYMPTOMS ON LEAVES

Leaf Curling.—The earliest symptoms of curly top to appear in most diseased beets is an inward rolling of the lower and outer margin of the youngest leaves (fig. 1). Later the entire blade may show a pronounced inward curling toward the mid-rib. There is a considerable variation as to the number of curled leaves occurring in older diseased beets, but very often the outer full-grown leaves do not show this character (fig. 3). A beet showing curly leaves and no other

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[2] Stechlings are small beet roots used for commercial seed production.

[3] The term 'mother beet,' commonly applied to beets used for seed production, implies that the beet flowers possess only pistillate parts, while, as a matter of fact, each flower bears both staminate and pistillate organs. It is therefore suggested by Townsend (in U. S. Dept. Agr. Bur. Plant Industry Bul. 122) and by Shaw (in U. S. Dept. Agr. Bur. Plant Industry Bul. 181) that in place of the expression 'mother beet,' the more accurate and simpler term 'seed beet' be used.

Fig. 1.—Youngest leaves of sugar beet affected with curly top, showing inward rolling of lower and outer margin.

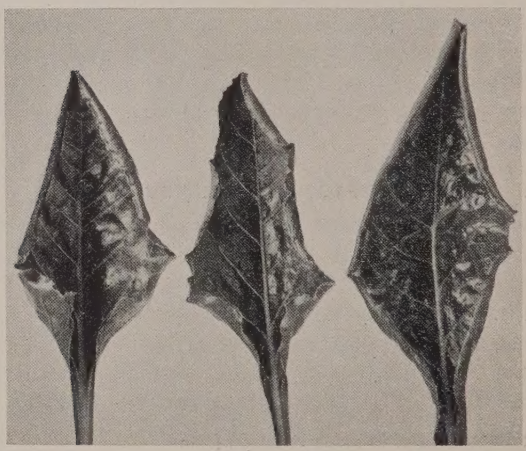


Fig. 2.—Healthy Sugar-beet leaves showing inward rolling of lower and outer margin.

symptom of the disease is not always a curly-top beet, for perfectly healthy beets may show the same characteristics (fig. 2).

The foliage of some diseased beets shows an outward rolling of the margin of the leaves and an outward puckering of the blade between the veins. Sometimes the two types of leaf curl are combined, the blade curling outward and the margin inward.

Fig. 3.—Curly-top beet showing inward curl of younger leaves but no marked curling of outer leaves.

Blister-like Elevations.—A symptom of curly top which sometimes develops on the leaves of beet seedlings is small blister-like elevations. In beet seedlings with four to six leaves including the cotyledons, these blisters may appear simultaneously on the outer and the inner leaves, or on an outer leaf before the youngest leaf is developed, or on only the youngest leaf. The blister-like elevations sometimes develop in two days after the beet seedling is infected with the disease.

Transparent Venation.—A reliable and constant symptom of curly top plainly visible to the eye is a transparent network of minute veins (pl. 1, *B*), generally occurring on the innermost or youngest leaves of the beet. At the beginning this symptom may be confined to a portion of the youngest leaf, but in a few days, in vigorously growing beets, the entire leaf is affected. Sometimes the cleared veinlets and blister-like elevations appear simultaneously on the youngest leaf of beet

seedlings. The transparent veinlets sometimes appear on the youngest leaf of beet seedlings within two days after infection with the leafhopper. In older beets in the field, this symptom may develop in from one to two weeks or longer after infection. A diseased beet may retain the transparent venation on the leaves during the entire season and show no other symptom. Late-infected beets suffering from lack of moisture may show the cleared veinlets on the youngest leaves and no other symptom.

Confusion of Transparent Venation with Insect Injury.—During a severe infestation of aphids on beets a white venation resembling somewhat the transparent venation of curly top, occasionally develops on the leaves. This white venation has been observed in the Sacramento Valley before the migrations of the beet leafhoppers have occurred and is not associated with curly top. Thrips with their rasping and sucking mouth-parts destroy small streaks of the epidermis of beet leaves and the injury has been mistaken for the cleared veinlets of curly top. The leaves showing thrip injury are frequently covered with numerous fine specks of excrement.

Protuberances on Leaves.—Another reliable and constant symptom of curly top is the roughened appearance of the lower surface of the leaves, developing usually after the veinlets have become transparent. A closer examination of this roughened condition upon its first appearance reveals numerous small elevations on the veins resembling tiny warts (pl. 2, *A* and *B*). As the disease progresses, nipple-like papillae and knot-like swellings (pl. 2, *C*) resembling galls develop here and there on the distorted veins. The diseased leaves are dark, dull green in color, thick, crisp, and brittle.

Exudation from Leaves.—When a large number of curly-top beets are examined in the field an occasional plant may show a few drops of clear viscid liquid exuding from the petioles, mid-rib, or veins on the lower surface of the leaves. Later this liquid becomes black (pl. 2, *D*) and sticky, and upon drying forms a brown crust. Similar observations have been made in the greenhouse with curly-top beets which had been infected with beet leafhoppers in cages.

After beets affected with curly top have received the first irrigation by the check and border or flooding method, it was observed in some fields that this syrupy substance oozed out in many beets. In all probability, the water which the roots absorbed increased the turgidity and ruptured the epidermis, allowing the drops to exude from the wounds. One badly diseased beet field planted in December

had been sub-irrigated for a month and was also irrigated by flooding on May 8, 1919. On May 15, when the next visit was made, the field was swarming with enormous numbers of insects that were attracted to the sweet drops of beet juice. Large numbers of ladybird beetles were feeding on the juice exuding from the foliage and not upon scale insects as Behr assumed, according to Linhart.[4]

Yellowing.—When curly-top beets are irrigated they sometimes show a temporary improvement, but later the leaves often turn yellow. The rapid yellowing of the foliage shortly after irrigation may be associated with the exudation of sap. Two December-planted beet fields showing 100 per cent curly top had been sub-irrigated for a month and were also irrigated by flooding on May 8 and 23. The foliage of one field was decidedly yellow on May 15, and the other on May 25.

It is not to be inferred, however, that the yellowing of the foliage occurs only after the fields have been flooded with water; the leaves of diseased beets, especially young plants, will turn yellow without irrigation. In early-planted beets the outer leaves may remain green for a month or longer after the beet leafhoppers have invaded the beet fields, but finally they turn yellow, then brown, and die prematurely. It is the outer, apparently healthy leaves that are functioning and making the growth of the beet in severe cases of curly top.

During the ripening period of healthy sugar beets, a general yellowing of the foliage occurs, and often the leaves present a drooping appearance. Maturity is also indicated by a browning of the outer leaves, which later become dry. The normal yellowing of the foliage at maturity has often been mistaken for a symptom of curly top by beet growers.

The yellowing of the foliage of sugar beets is often associated with the attacks of the sugar beet nematode (*Heterodera schachtii*) on the heavier soils and the root-knot nematode or gallworm (*Heterodera radicicola*) on the lighter soils. In the early infestation, the leaves become dark green, as if suffering from moisture. In severe infestations the leaves wilt, the outer leaves die, and the inner leaves remain small, and finally die also. In nematode-infested beet fields, barren areas with all of the beets destroyed gradually increase in size from year to year.

Sun-Scorched Foliage.—During very hot days in the San Joaquin and Sacramento valleys, and interior regions of the Salinas Valley,

[4] Linhart, G. Die californische Rübenkrankheit. Oesterr. Ungar. Zeitsch. f. Zuckerindustrie und Landwirtschaft **30**:26–42. 1901.

the sugar-beet foliage wilts and the outer leaves resting on the soil become sun-scorched, turn brown, and die. When the apparently healthy outermost leaves of badly diseased beets become dry owing to sun scald, there remains a tuft of diseased leaves (fig. 4) and the beet root does not increase appreciably in size. The beet often becomes soft and loose in the soil, shrivels, and dies, leaving a woody shriveled peg (fig. 5, *C*) in the center of a hole in the ground. Small

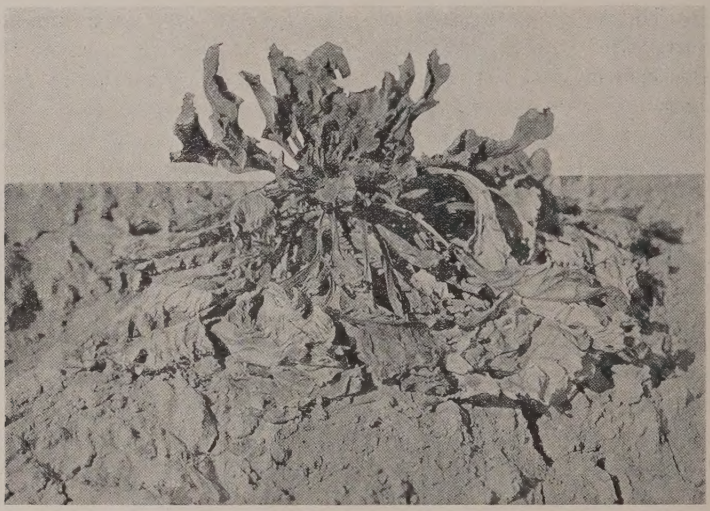


Fig. 4.—Curly-top beet with outer leaves dry from sun-scorch and with tuft of diseased inner leaves.

patches of dead beets soon appear in the field, giving a greater opportunity for other leaves to become sun-burnt and thus increasing the size of the barren areas as the season advances.

An experiment was performed in the field demonstrating that badly diseased beets made little growth after the outer apparently healthy leaves were cut off, leaving a tuft of diseased leaves with warty protuberances. The diameter of the beet root near the crown was measured with calipers every two weeks during the season. These mutilated beets made no appreciable growth, although they received two irrigations and thorough cultivation. Some of the check or control beets with outer leaves intact continued to grow and in a few cases developed into marketable beets, although badly diseased.

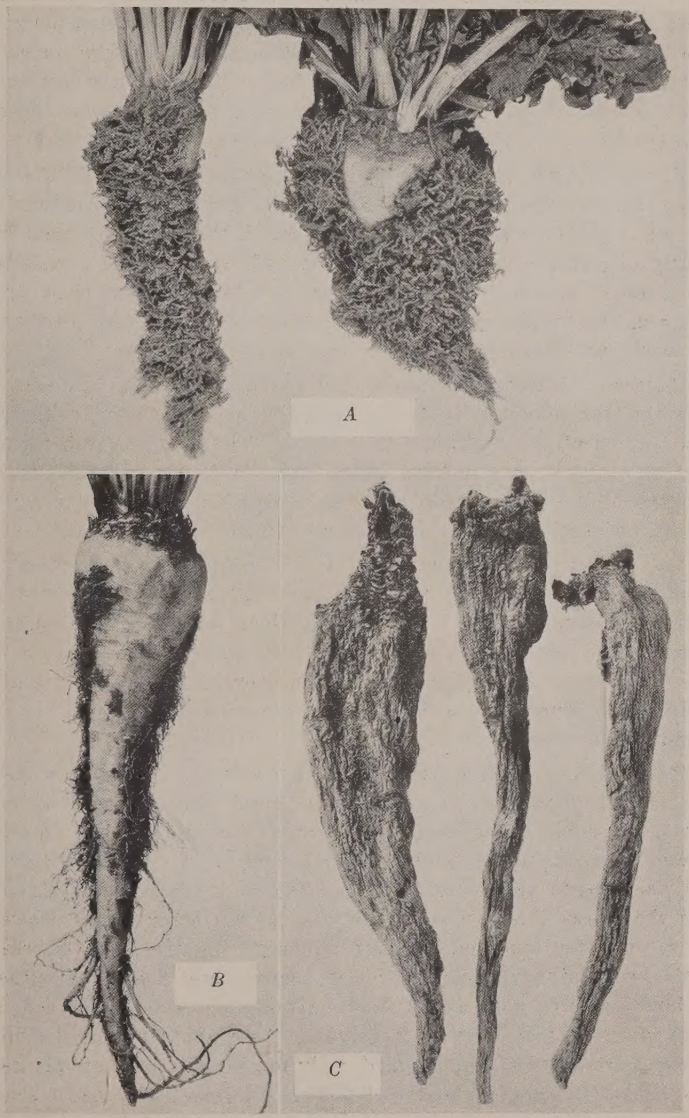


Fig. 5.—*A*, 'hairy,' 'woolly,' or 'whiskered' beets with soil clinging to rootlets. *B*, 'hairy' beet with soil removed, showing abundant rootlets. *C*, Woody shriveled beets that died owing to curly top.

Winter.—During the winter the leaves of early-planted beets are thick, and the reliable symptoms of curly top do not develop plainly. The cleared veinlets appear as heavy white branches, often on only a small portion of a leaf. In all probability, the relatively low temperatures, high humidity, and the few hours of actual sunshine retard the development of the disease.

Spring.—After the leafhoppers fly into the beet fields in the interior regions during the spring a mild form of curly top occasionally develops. Beets are sometimes found in which the cleared veinlets are faintly discernible on a small area of a leaf. Later in the spring, as the disease increases in the field, the symptoms become more pronounced, the transparent venation spreads over the entire leaf, and the warty protuberances become conspicuous.

Autumn.—During the autumn the youngest leaves do not always show the transparent venation; instead, this symptom may be limited to a portion of the somewhat older leaves. The warty protuberances may be confined to a portion of an outer leaf. During 1925 these symptoms were first observed on September 10 in the Sacramento Valley, but during October were common in badly diseased beet fields.

Later in the autumn the leaves which develop are dark green in color, the petioles are longer and the leaves are not so badly curled as during the summer. The beet fields lose their yellow appearance and become green, a condition which sugar-beet agriculturists describe as a recovery from the disease. The foliage, however, shows the reliable symptoms of curly top, although the symptoms may not always be found on the inner leaves.

Bud Leaves.—During years between outbreaks of the beet leafhopper, considerable emphasis has been placed upon the value of bud leaves, commonly called 'secondary' leaves, in relation to the disease. It was assumed in the delta or island country of the San Joaquin and Sacramento valleys that the bud leaves developed so profusely that the diseased beet would grow even if the other leaves showed severe curly-top symptoms. Observations during the 1925 outbreak of the beet leafhopper showed, in late-planted beet fields, that either no bud leaves or only a few small leaves grew from the crown of badly diseased beets during the season. As a general rule, the bud leaves showed typical symptoms of curly top in early and late-planted beet fields. In early-planted beet fields, bud leaves may be of some value, especially when the outer leaves of diseased beets become badly sun-scorched.

Relation to Moisture.—Beets with warty protuberances on the outer leaves and not showing the transparent venation on the inner leaves were removed from hard sandy soil at Manteca and planted in 6-inch pots in the greenhouse. The pots were watered in saucers so that the soil was saturated with moisture. In some cases the new leaves developed the cleared veinlets, but in a few beets no symptoms appeared on the youngest leaves. The potted beets with no visible symptom on the inner leaves were now transferred to a chamber containing dry sand. At the end of one week the transparent veins appeared on the inner leaves. The protuberances remained on the outer leaves throughout the entire experiment.

In another experiment, beets with warty protuberances on the outer leaves and showing the transparent network of minute veins on the inner leaves, were handled as in the previous experiment. In a few beets the new leaves showed no visible symptom of the disease, but when the soil became dry, the cleared veinlets appeared on the youngest leaves.

Irrigation.—The relation of the symptoms of curly top to irrigation was recorded in several beet fields and general observations were made in many beet districts, during the 1919 outbreak of the pest. In one experiment 200 beets were marked in several beet fields planted early and late. The development of the symptoms of curly top of each beet was noted and the measurement of the beet root below the crown taken every 10 days.

After beets planted in January on fertile sandy loam at Manteca received the first irrigation by flooding, no symptoms of the disease were visible on the newly developing leaves of some of the beets. The beets made a vigorous growth after each irrigation and averaged 10 tons per acre. On the other hand, an adjacent field low in fertility separated by an irrigation ditch, also planted in January, and irrigated at the same time, failed to respond to the water.

In a beet field planted in December on sandy loam at Hatch Station, over one-half of the crop was infected with curly top by the dark adults wintering in the cultivated areas before the pale green leafhoppers of the spring broods flew into the beet fields. The transparent venation appeared on the young leaves which developed after irrigating the field by the flooding method. The beets were grown on a strong alkali sandy soil and were plowed under after the first irrigation.

The relation of the symptoms of curly top to sub-irrigation was observed in a beet field in the San Joaquin Delta consisting of 40

acres planted late in May after the spring flights had ceased during 1925. The optimum moisture conditions were kept in this field after the beet seedlings appeared above the surface of the soil. The beets were sub-irrigated and the water was then allowed to drain from the field so that the soil did not become soggy. The ditches were kept filled with fresh water; water was not allowed to become stagnant. The flights of the summer-brood adults began on July 1, at the time when the beets were thinned. An examination of the percentage of curly top on July 31, showed that 86 per cent of the beets were diseased,—76 per cent in the transparent venation stage and only 10 per cent with warty protuberances on the leaves. Beets were found with no visible symptoms of curly top on the youngest leaves, but with the cleared veinlets on the somewhat older leaves. In some instances the transparent venation was so faint that one hesitated to pronounce the beet diseased. The exudation of sap occurred from the petioles and mid-ribs of some of the leaves showing the cleared veinlets. The beets were making a vigorous growth and the leaves were almost covering the rows on July 31. These beets were grown on a muck and peat soil where large tops develop and the leaves do not turn yellow as rapidly as on the heavier soils. An examination of this field on September 10, showed many diseased beets with dark, green, curled inner and yellow outer leaves. The yield of the 40 acres averaged 10 tons per acre.

It is not to be assumed that this method of irrigation served as a control of curly top in this beet field. The important facts to be emphasized are (1) a low percentage of curly top occurred until the summer-brood adults invaded this field; (2) a high percentage of beets were not stunted and remained in the transparent-venation stage and were making a vigorous growth regardless of the disease; (3) a fresh supply of water around the roots was probably more beneficial than stagnant water; and (4) a muck and peat soil rich in organic matter supplied an abundance of plant food.

When the beet leafhoppers are at their maximum in numbers as occurred during the 1919 and 1925 outbreaks of the pest, the application of water by the different methods of irrigation will not check the progress of the disease in the interior regions of California, with late-planted, badly diseased, stunted beets that have warty protuberances on the lower surface of the curled leaves and nipple-like papillae and knot-like swellings on the distorted veins. During 1919 one farmer in the southern part of the San Joaquin Valley flooded his beet field seven times but at the end of the season the crop was not

worth harvesting. Early-planted diseased beets growing in rich soil usually respond to irrigation unless the outer leaves become badly sun-scorched. It has been demonstrated in the Salinas Valley with early-planted diseased beets that better yields can be obtained with repeated light furrow irrigations than with the flooding method. Where proper conditions prevail, sub-irrigation offers an ideal method of applying the water, and is far superior to the flooding method.

In the Fog Belt.—In the fog belt it is impossible to determine the percentage of curly top accurately in some fields. In some instances the transparent venation of the youngest leaves is so faint that one hesitates to state whether or not the beet is affected with the disease. In other cases only a small area of the leaf shows the cleared veinlets, or one-half of a leaf on one side of the mid-rib is affected and the other half shows no trace of the disease. Beets which are not irrigated develop thick leathery leaves in the fog-belt regions and the foliage symptoms of curly top are of little value in determining accurately the percentage of diseased beets. Leaves showing the nipple-like papillae and knot-like swellings on the lower surface were rarely found in the fog-belt areas of Orange County.

During 1919 the beet leafhopper was captured on various species of saltbushes in every beet center in the fog-belt district in the southern part of the state. At Huntington Beach, *Eutettix tenellus* was taken on silverscale or fogweed (*Atriplex argentea expansa*) growing about 200 feet from the seashore. In the vicinity of the Southern California Sugar Factory at Dyer, and the Santa Ana Sugar Factory formerly at New Delhi, a few leafhoppers were taken in each sweeping on redscale or red orache (*A. rosea*).

During the general outbreak of the disease in 1919, the low percentage of curly top in many beet centers of the fog-belt districts was not in proportion to the number of beet leafhoppers present. In some localities in Orange County the beets seemed to be stunted or stopped growing, the foliage was yellow, often the leaves showed a suspicious inward curl, and yet reliable symptoms of curly top could rarely be found. The managers, agriculturists, and fieldmen attributed this condition to a shortage of rainfall, stating that the rains were scattered and the surface soil never became thoroughly saturated with water and remained dry during the rainy season, or the surface and subsoil moisture never met. At the Weather Bureau office at Los Angeles, the information was received that in normal years of rainfall the maximum level of the water table is highest in July and at its

minimum in January. In July of 1919, there was present the least amount of water available for irrigation in fifteen years and the wells became dry.

Although drought was a very satisfactory explanation for the condition of some of the beet fields in the fog-belt areas, nevertheless, it was deemed advisable to transplant some of the beets to the greenhouse at Berkeley. In a beet field planted in January and February adjacent to the Southern California Sugar Factory, curly top was rare; not more than one-half dozen diseased beets were found in an acre. The beets had been irrigated three times and the leaves were not too thick to show the reliable symptoms of the disease. Beets showing an inward curling of the leaves were selected and transplanted to the greenhouse. Five transplanted beets developed the protuberances on the lower surface of the leaves, and 21 were healthy.

On August 12 a beet field near Santa Ana was examined for curly top. A portion of this field had been planted in January; 12 per cent of these beets showed curly top symptoms, though often only a small area on one leaf was affected. The rest of the field had been replanted in February because the seeds planted in January had failed to sprout owing to dry soil. The field had received two irrigations after planting, but at the time of examination the field was so dry that growth had ceased. Examination was made of 150 of the replanted beets that were growing near redscale or red orache on which the beet leafhoppers were abundant. Curly-top symptoms were found on 37 beets, or 24.7 per cent. The remainder, which showed no reliable symptoms of curly top, were transplanted to the greenhouse at Berkeley on August 15. They were watered to stimulate growth. Warty protuberances developed on 52 beets, while 61 remained healthy. In most of the diseased plants all of the leaves of the inner whorls showed curly-top symptoms, and not merely the youngest leaves.

This experiment is a demonstration of the fact well known in curly-top localities—that in fields which have been allowed to become so dry that growth has ceased, curly-top symptoms do not appear, but when growth is stimulated by irrigation, a large percentage of the beets may develop symptoms,[5] if the leafhoppers have been present in the field.

[5] This should not be confused with the relationship of curly top to soil *saturated* with water, which seems to check the development of symptoms under greenhouse conditions.

Fig. 6.—Curly-top beet with the margins of the leaves showing an outward rolling and puckering of the blade between the veins. The petioles of the leaves are shortened and arranged to form a rosette. Rosettes sometimes have numerous dwarfed, flat leaves without puckering.

ABNORMAL BEET FOLIAGE OFTEN CONFUSED WITH CURLY TOP

Roll Leaf.—A type of abnormal beet foliage designated as roll leaf by R. E. Smith shows an inward rolling and puckering of the leaves and develops commonly in sugar beets grown under cover in the greenhouse. When infective beet leafhoppers are confined in a cage enclosing a roll leaf beet, typical curly-top symptoms develop, but noninfective hoppers are not able to transmit roll leaf to healthy beets.

Rosette.—Beets late-infected with curly top sometimes develop numerous dwarfed, flat leaves with short petioles forming a rosette, but perfectly healthy beets may show the same characteristics in beet fields in which the soil is too dry. A curly-top rosette may show typical symptoms, namely, the transparent venation and protuberances on the lower surface of the leaves. A rosette affected with curly top may show either an inward or an outward curl of the leaves (fig. 6).

Fig. 7.—Side view of beet affected with downy mildew (*Peronospora schachtii*). showing dwarfed and curled youngest leaves. Insets show the curled and malformed leaves enlarged.

Downy Mildew (Peronospora schachtii).—Downy mildew causes a dwarfing and curling of the inner leaves (fig. 7) of early-planted beets and a temporary checking of the growth of the plants. The fungus is visible to the eye as a violet mildew on the lower surface of the affected leaves. During the late spring rains in 1925, beets affected with downy mildew were unusually common in the Sacramento and the Santa Clara valleys. During the summer, however, beets affected with downy mildew recovered in the Sacramento Valley, and the leaves which developed later were not dwarfed, curled, or malformed.

Mosaic Disease.—Boncquet[6] described two types of diseases in California, namely, mottled leaf and black edge or black tip of sugar beets. According to Robbins's[7] description and illustrations, these two

[6] Boncquet, P. A. *Bacillus morulans* n. sp. A bacterial organism found associated with curly top of the sugar beet. Phytopathology **7**:269–289. 1917.

[7] Robbins, W. W. Mosaic disease of sugar beet. Phytopathology **11**:349–365. 1921.

types of diseases are symptoms and malformations of sugar-beet mosaic. The principal symptom of mosaic disease of sugar beets is mottling of the leaves (pl. 3, *C*) which may or may not be associated with malformation. Aphids carry the infective principle.

Sugar beet mosaic is distinct from curly top. Successive generations of beet leafhoppers non-infective as to curly top have been bred on mottled-leaf and black-edge or black-tip beets, and the hoppers were then transferred to healthy beets, but not a single case of curly top developed. Furthermore, *Eutettix tenellus* was not able to trans-

Fig. 8.—Mosaic disease of sugar beet; the two leaves on the left are malformed, with black tips; the three leaves on the right have blades reduced to but little more than a continuation of the petioles, and show both black edges and black tips.

mit mosaic of sugar beets. On the other hand, when infective leafhoppers were allowed to feed on mottled-leaf and black-edge or black-tip beets, typical curly-top symptoms appeared.

In the Santa Clara Valley a mottling occurred during 1923, in which the normal green color of the leaf was spotted with small pale yellow or white areas (pl. 3, fig. 3) and also with large blotches irregular in shape, similar to those shown in plate 3, *A* and *B*. Associated with this type of mottling, was a dwarfing and malformation of the leaves with black tips (fig. 8) or black edges or both, and sometimes a reduction of the blade until it was represented by but little more than a continuation of the petiole (fig. 8).

Beets apparently affected with another type of mosaic disease were sometimes found in the field with filiform, curled, and malformed leaves, but without mottled leaves.

In some of the beet fields of the Sacramento Valley, 50 per cent of the sugar beets showed a pronounced mottling of the leaves in 1919. The mottling was characterized by a spotting of the normal green color of the leaf with pale yellow or white areas usually irregular in shape

Fig. 9.—Left, two beet leaves showing injury caused by a green leafhopper (*Empoasca flavescens*); right, normal leaf.

and varying considerably in size (pl. 3, *A* and *B*,) Malformations of the leaves did not develop with mottled-leaf beets during the season. Difficulty was sometimes experienced in the field in determining the percentage of curly top when mottled-leaf beets also showed the transparent venation of curly top. Beet leafhoppers non-infective as to curly top failed to produce mottled leaf in healthy beets, while infective hoppers transmitted typical curly-top symptoms to mottled-leaf beets.

Mosaic may be confused with the injury to sugar-beet leaves caused by a green leafhopper (*Empoasca-flavescens*). This leafhopper sucks the juice from the leaves causing irregular white areas (fig. 9).

SYMPTOMS ON BEET ROOT

Hairy Root.—When a badly diseased beet is pulled from loose sail, particles of dirt sometimes cling to the rootlets (fig. 5A, p. 9) and shake off with difficulty. It is evident that there is an increase in the number of rootlets (fig. 5B), a condition which has been described as 'hairy' or woolly root' or 'whiskered beets.' In harder soil these roots often tear off when the beet is pulled.

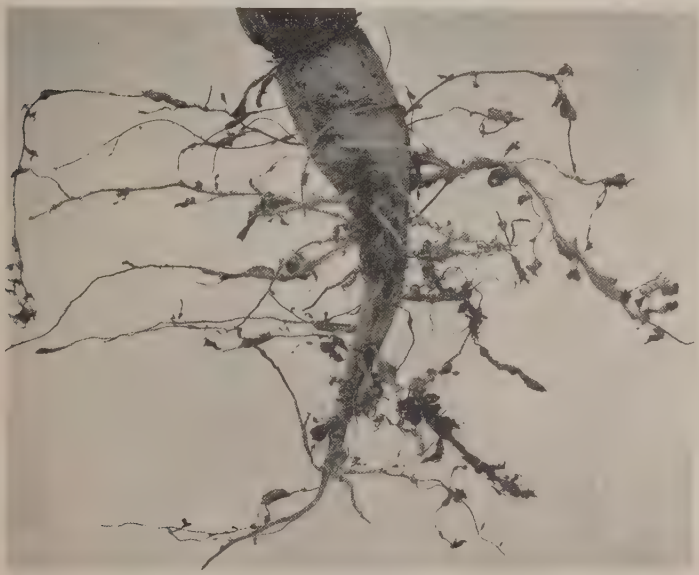


Fig. 10.—Root-knot nematode (*Heterodera radicicola*) showing irregular swellings; the appearance of the beet after the roots die back is shown in plate 4, *B*.

Bearded or Hunger Roots.—If the root system of a plant infested with sugar-beet nematode (*Heterodera schachtii*) is carefully removed from the soil, it is evident that the beet grows a large number of rootlets which are called bearded or hunger roots in Europe, and resemble the hairy or woolly root or whiskered beets of curly top. Attached to the bearded or hunger roots are small white or brown female nematodes (pl. 4, *A*) which are absent on the hairy roots of curly top.

The root-knot nematode or gallworm (*Heterodera radicicola*) causes irregular swellings on the roots (fig. 10) in which the eelworms are present. The roots often die back (pl. 4, *B*) owing to lack of nourishment.

Darkened Rings.—A cross-section of a diseased beet often shows black concentric rings which alternate with light circular areas. A longitudinal section shows the dark discoloration extending lengthwise through the beet. According to some writers, the successive black rings mark the phloem portion of the fibro-vascular bundles.

Soft and Rotted Beets.—Irrigation or badly diseased beets, especially when the beet roots become soft and begin to shrivel in the soil,

Fig. 11.—Curly-top beets which were irrigated, resulting in a rotting of the taproot. Longitudinal and cross sections of rotted beets are shown on the right.

results in a rotting of the tap roots (fig. 11). The tareman at the beet dumps removes the rotted portion of the beet, thus increasing the percentage of tare or dirt. Soft beets rot in transportation and in the bins.

SYMPTOMS IN SEED BEETS

Dead Heads.—When stechlings and mother beets affected with curly top are transplanted, they often fail to develop seed stalks or develop only very small seed stalks (fig. 12), a condition which growers call 'dead heads' or 'sports.' The seed stems may bear a small quantity of seeds, but often the plant dies before mature seeds develop.

An experiment was conducted to determine the effect of curly top on stechlings infected after transplanting. Healthy stechlings were planted in a 10-inch flower pot and after the leaves developed, or in

some cases after the seed stalks appeared, infective beet leafhoppers were allowed to feed on the foliage. After reliable symptoms of curly top appeared, the stechlings were transplanted in the field at Berkeley. It was found that the infected stechlings developed seed stalks about one-half of the height of those of healthy stechlings used as a check or control (fig. 13).

Fig. 12.—Seed beet affected with curly top, showing short seed stalks.

The reliable symptoms of curly top just described are characteristic of stechlings before transplanting. In seed beets, however, there is often considerable difficulty in detecting the transparent venation and the protuberances on the lower surface of the leaves, but these symptoms of curly top are usually discernible on the bud leaves growing at the crown of the transplanted stechlings and mother beets and on the leaves of the younger shoots.

Dead Germs.—During the 1919 outbreak of the beet leafhopper seed growers often discussed the affect of curly top on the germs in beet seed. The germs were often black and shriveled.

Fig. 13.—Left, healthy stechling showing normal length of seed stalks; center, stechling infected with curly top in the greenhouse and then transplanted in the field, showing seed stalks about one-half of the height of those of healthy stechlings; right, diseased stechling removed from the stechling field and then transplanted in the field, showing very short seed stalks.

PRACTICAL APPLICATION

Percentage of Curly Top.—In checking up the percentage of curly top in a field of beets or stechlings, 50 or 100 plants in a row are usually selected, representing as nearly as possible typical conditions in the field. If a more accurate estimate of the percentage of diseased beets is desired, another 50 or 100 plants are examined, in the other parts of the field. The innermost or youngest leaf is pinched off with the fingers and the lower surface of the leaf is held toward the eye and the upper side toward the sun. If the plant is affected with curly top, one can readily see the transparent network of minute veins. When a badly diseased beet shows the protuberances on the lower surface of its leaves, this is recognized by a trained eye and no further evidence is required.

During the general outbreak of curly top in 1919, numerous calls were received from sugar companies to examine the curly-top situation. An attempt was made to train the agriculturists and fieldmen with reference to the reliable symptoms of the disease so that they could check up the percentage of diseased beets in their fields. The method employed was to have the agriculturist or fieldman tear off the innermost leaf and pronounce the beet either healthy or diseased, and then the leaf was handed to the writer for verification. Instead of the requests from sugar companies becoming less numerous, the calls became more urgent, especially in the case of diseased stechlings. To familiarize agriculturists and fieldmen with the transparent venation of curly top in a few days' work with them in the beet fields proved to be a failure in every case.

An agriculturist or fieldman who is thoroughly acquainted with the symptoms of the disease can save thousands of dollars to sugar companies and to farmers by stopping further agricultural operations when a severe outbreak of curly top occurs. But the decision to plow under a crop of beets, even when they show a high percentage of disease, is extremely critical, for diseased beets sometimes develop into marketable beets, and such recommendations should only be made by thoroughly competent men. Fields in which a high percentage of curly top is present before or shortly after thinning should be plowed under. When late-planted beets stop growing and are stunted, when the badly curled leaves with shortened petioles show a tendency to spread flat upon the ground, when the lower surface of the leaves

show warty protuberances, nipple-like papillae, and knot-like swellings on the veins, and when the general appearance of the field is yellow, even though the inner leaves are dark, dull green in color, the field should not be irrigated, but the beets should be plowed under immediately.

The field should not be replanted with beets during a severe outbreak of the beet leafhopper, as the summer-brood adults will destroy the second planting, as occurred during the 1919 and 1925 outbreaks. The field should be replanted with a cultivated plant which is resistant or immune to curly top. As demonstrated in a previous paper[8] pink beans are highly resistant to curly top and can be planted late to mature in time to make a full crop. It has not been possible to transmit curly top to any plant in the Gramineae or grass family. The following economic plants are immune to curly top and can be planted throughout June in the delta district, on the authority of W. W. Mackie: grain sorghums such as milos, Egyptian corn, feterita, and hegari; Proso millet, sweet corn, and broom corn. All varieties of lettuce grown in California are immune to curly top and any variety can be used as a replant in the fog belt.

Fields of marketable diseased beets should be harvested as early as possible, especially when the outer leaves have become sun-scorched and barren areas appear in the field, and also fields in which the beets have become soft and loose and begin to shrivel in the soil.

In localities where more or less curly top occurs annually and in years when no general and widespread outbreak of the disease occurs, late-planted beets are apt to suffer more from the disease than those planted early. In the northern part of the San Joaquin Valley, the pale green beet leafhoppers of the spring broods fly from the plains and foothills usually toward the end of April, and when beets are planted during late March and April, the crop either yields a low tonnage or is not worth harvesting. During 1920 two fields were selected, one planted in late March and the other in April, and the percentage of curly top was determined at least once during each month. On May 1, an average of one leafhopper was found on each beet in the late March planting and one adult to 6 or 7 beets in the April planting. The percentage of curly top increased as follows:

Beets planted late in March–May 1, 6 per cent; May 14, 16 per cent; June 1, 60 per cent; June 16, 92 per cent; July 1, 100 per cent.

Beets planted in April–May 1, 0; May 14, 2 per cent; May 28, 8 per cent; June 16, 30 per cent; July 1, 94 per cent.

[8] Severin, H. H. P. Some host plants of curly top. Hilgardia 3:339–392. 1928.

In neither field were the beets harvested. It is not to be assumed that the rapid increase of curly top during the three months in which the observations were made was transmitted entirely by the spring-brood adults which invaded the beet fields; it was associated with the emergence of the summer-brood adults.

When the beet leafhoppers are at their maximum in numbers, the percentage of curly top which develops depends upon the number of hoppers on each beet. During the 1919 outbreak, at least ten adults were present on each beet in the late plantings at Connor, situated near the Tehachapi Mountains in the southern part of the San Joaquin Valley. The spring flights of the leafhoppers began on April 8; on April 17, 40 per cent of the beets showed curly-top symptoms and on May 7, 96 per cent were diseased in one field.

Number of Leafhoppers in Beet Fields.—Considerable emphasis is placed upon the determination of the number of leafhoppers in a beet field during the spring flights, by the entomologists of the Spreckels Sugar Company, and a crop is sometimes plowed under, before a high percentage of curly top develops, if there is more than one adult to 20 beets in 100 feet of feet row before or shortly after thinning. According to Schwing[9] "if beets have not been thinned or have just been thinned, when the adults invade the fields, the possibility of a crop is very problematical; in fact, a failure is almost a certainty when one leafhopper to 20 beets are present. If beets have been thinned and possessed not over 16 leaves, with the same number of insects, the crop is still doubtful and the beets may or may not pay for harvesting. In a case like the latter, beets had best be left to complete their growth if there is doubt as to the success of a crop planted at this time."

The method of determining the number of beet leafhoppers in 100 feet of beet row is to disturb the foliage by moving the fingers among the leaves, while the observer crawls along the row of beets on his hands and knees. The number of bugs can be determined approximately with small beets up to and shortly after thinning, but with larger beets this method this method is unreliable. During cloudy, cool mornings the determinations are more accurate than on warm sunshiny mornings, when the activity of the adults makes observation more difficult and less accurate, owing to the fact that other species of leafhoppers are often abundant in the beet fields. The hoppers

[9] Schwing, E. A., and W. J. Hartung. Utilization of systematic observations on beet leafhopper (*Eutettix tenella* Baker) and curly leaf. Jour. Econ. Ent. 15:365–368. 1922.

are more active at sunset, and a higher percentage of insects are recorded in the beet fields than at any other time of the day. During an outbreak, the number of insects increases over a period of from 4 to 8 weeks in a natural breeding area and it is impossible to estimate accurately the ever-increasing hordes of bugs later in the spring. Although the number of adults can be determined approximately in beet fields when no general outbreak occurs, nevertheless the plowing under of a crop of beets until a high percentage of curly top developed is not recommended.

SUMMARY

The reliable symptoms of curly top plainly visible to the eye are the clearing or transparency of the minute veins on the youngest or innermost leaves in the early stages of the disease and wart-like protuberances on the lower surface of the leaves in the later stages of the disease.

Beets planted during March and April in a natural breeding ground of the beet leafhopper, such as the San Joaquin or upper Salinas valleys, are usually a failure and will not respond to irrigation when a high percentage of curly top occurs.

Early-planted diseased beets growing in rich soil usually respond to irrigation unless the outer leaves become badly sun-scorched. It has been demonstrated in the upper Salinas Valley that with early-planted diseased beets better yields can be obtained by repeated light furrow irrigations than by the flooding method.

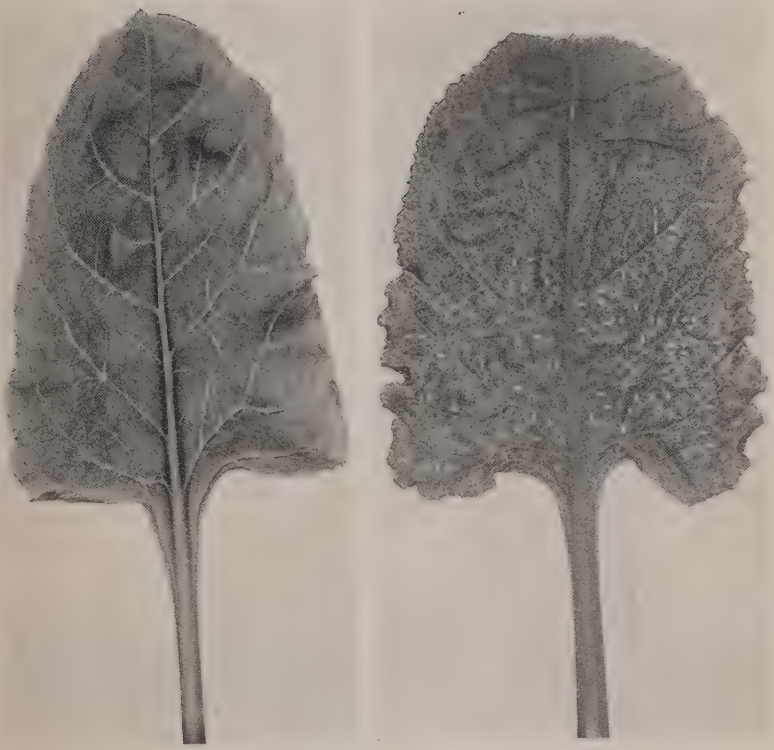
Beet fields in which a high percentage of curly top is present before or shortly after thinning should be plowed under, and replanted in pink beans, grain sorghums such as milos, Egyptian corn, feterita, and hegari; Proso millet, sweet corn, broom corn, or lettuce.

PLATE 1

Sugar Beet (*Beta vulgaris*)

A, Beet leaf showing normal venation.

B, Beet leaf showing the transparent network of minute veins usually present on the youngest leaves of curly-top beets.



A *B*

PLATE 1

PLATE 2

Sugar Beet (*Beta vulgaris*)

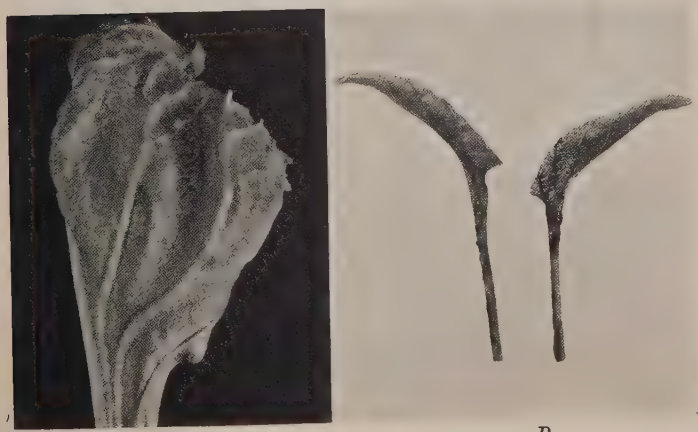
A, Leaf from curly-top beet showing small wart-like elevations on the veins, giving the lower surface of the blade a roughened appearance.

B, Small wart-like protuberances limited to the lower right side of the beet leaf.

C, Leaf from curly-top beet showing nipple-like papillae and knot-like swellings on the distorted veins.

D, Leaves from curly-top beet showing black liquid exudation on petioles and veins.

A B



C D

PLATE 2

PLATE 3

Mosaic Disease of Sugar Beet (*Beta vulgaris*)

A, Mottled leaves characterized by a spotting of the normal green color with pale yellow or white areas usually irregular in shape.

B, Mottled leaf enlarged.

C, Mottled leaves with small green round areas typical of mosaic, and large irregular blotches.

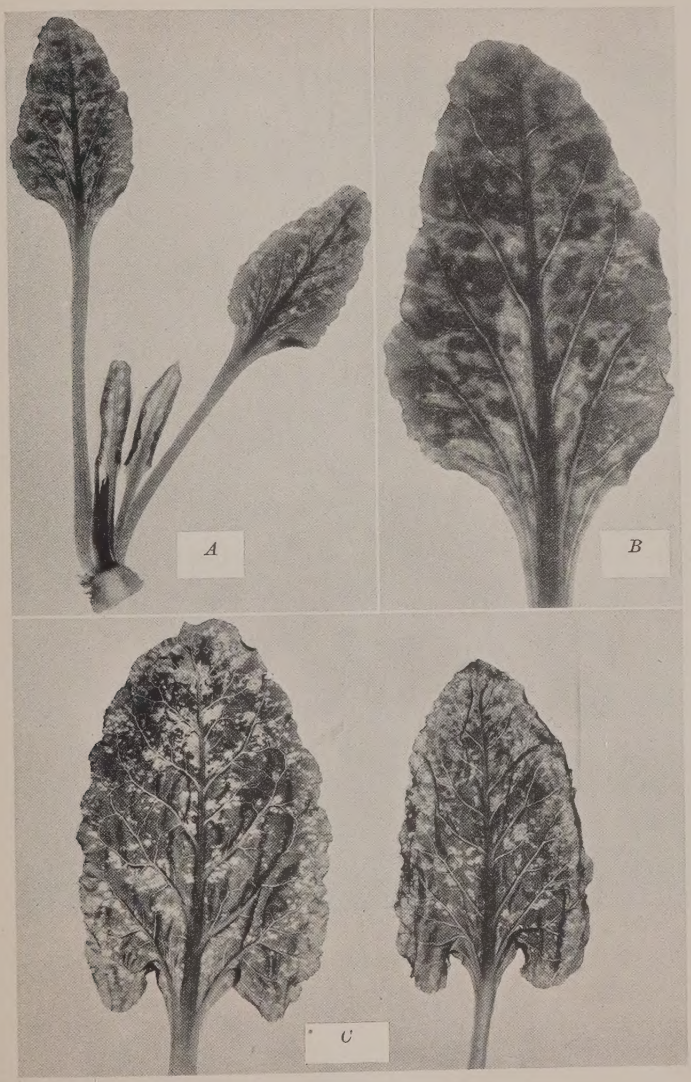


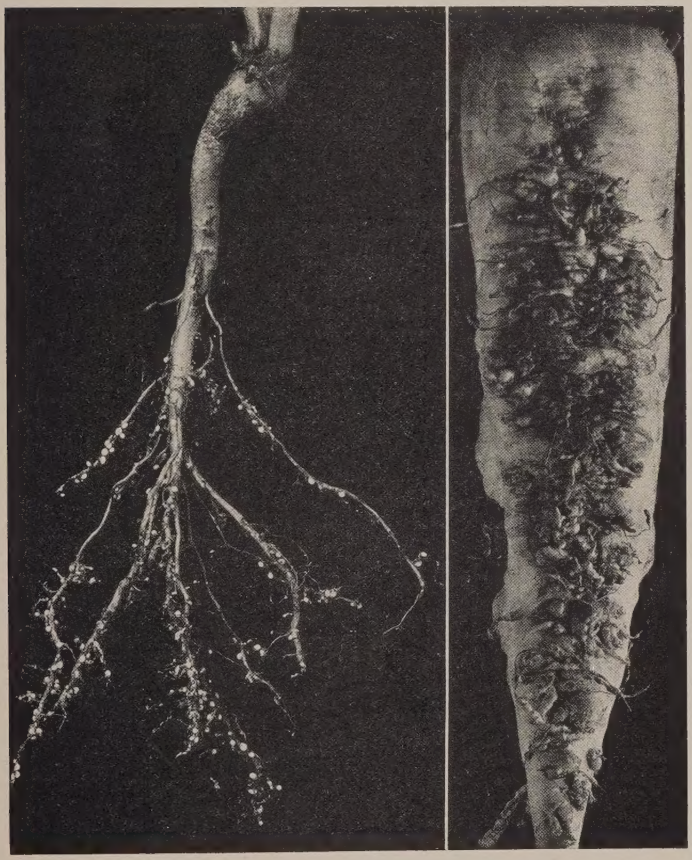
PLATE 3

PLATE 4

Beet Nematode (*Heterodera schachtii*) and Root-Knot Nematode (*Heterodera radicola*).

A, White female beet nematode on hairy roots.

B, Root-knot nematode showing irregular swellings in which the eelworms are present. The roots have died back owing to lack of nourishment.



A *B*

PLATE 4